Properties of Meander Coplanar Transmission Lines

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Abstract— **Experimental results for a new type of coplanar transmission line on insulating gallium arsenide, applicable to the miniaturization of MMIC's, are presented. The center conductor of the transmission line has the form of a meander line, and results in an increased inductance per unit length of coplanar line. Low propagation velocities in the range $0.5 - 1 \times 10^{10}$ cm/s have been measured. Lines of different dimensions have been characterized by on-wafer S-parameter measurements and equivalent circuit modeling.**

I. Introduction

TRANSMISSION lines are extensively used as coupling and tuning elements in monolithic integrated circuits at microwave and millimeter wave frequencies [1]–[2]. Since the effective dielectric constant of materials such as gallium arsenide (GaAs) and indium phosphide (InP) is in the range 6–9, propagation velocities of about $1 - 1.2 \times 10^{10}$ cm/s are possible for microstrip and coplanar lines [3], [4]. This velocity however still results in large dimensions for monolithic integrated circuits, and thus in large chip sizes. Schemes for miniaturization have been suggested by a number of authors in the past [5], [6]. These methods however allow a reduction in size along only one dimension, that transverse to the propagation direction, specifically the width and the height of the line. It is the purpose of this letter to describe a new coplanar transmission line, along which signals travel up to a factor of two slower than on normal coplanar lines, resulting in a corresponding reduction in the length of the lines.

II. Experimental Results

The new coplanar transmission line, with the center conductor in the form of a meander line, is illustrated in Fig. 1. The parameters ground-to-ground plane spacing d, gap s, and meander line width m were varied. The lines were produced on 0.5-mm thick, high-resistivity ($10^7 - 10^8$ Ohm·cm) gallium arsenide substrates. The metallization of the lines was 200 Å titanium, followed by 4000 Å gold. The lines were layed out to permit on-wafer probing with millimeter-wave coplanar probes (CASCADE). The S-parameters were measured with a HP-8510C network analyzer over the range 0–40 GHz. The measured S-parameters were then fitted to those obtained from an equivalent circuit model, using EESOF-LIBRA software. The circuit model of the transmission line consisted of 100 sections of the classical series inductance L, series resistance R, parallel conductance G, and parallel capacitance C model [7, p. 249], with the exception that the resistance R was modeled as a frequency dependent resistance of the form $R(f) = R_o f^n$ [8]. The conductance G was found to be negligible in the range above 1 GHz. The inductance L is the sum of the internal and the external inductance, with the internal inductance decreasing with frequency and being negligible above approximately 10 GHz.

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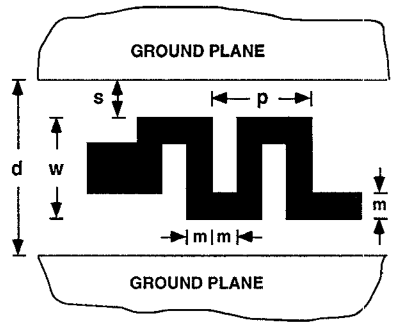

Fig. 1. Top view of coplanar transmission line with meander center conductor.

Two sets of lines, with ground-to-ground spacing d of 60 and 120 μm were evaluated. Centerline widths m of 10 and 20 μm were used. The gap s was varied between 5 and 40 μm. For clarity, we shall present only some representative data for four lines with $d = 120$ μm and $m = 20$ μm, where the gap s was 10, 20, 30, and 40 μm.

The measured real and imaginary parts of the input impedance Z_{in} of a line, with parameters as indicated, where t is the metallization thickness and l is the length of the line, are illustrated in Fig. 2. Also shown are the calculated values of the real and imaginary parts of the characteristic impedance Z_c of the line. These were calculated from a knowledge of the propagation constant $\gamma(f) = \alpha(f) + j\beta(f)$, and the capacitance C, which does not change with frequency. As has been shown [8], above a few GHz, the attenuation is well approximated by $\alpha(f) = a_o f^n$, and the phase constant by $\beta(f) = bf$, such that $\text{Re}(Z_c) = b(2\pi C)^{-1} = (vC)^{-1}$ and $\text{Im}(Z_c) = a_o(2\pi C f^{1-n})^{-1}$, where v is the phase velocity.

Fitting the circuit model to the S-parameter data, the line parameters, L and C, for four lines with differing gap dimension s are shown in Fig. 3. Inductances of nearly 1 nH/mm are obtained, which are considerably higher than the typical values of conventional coplanar lines (inductances of 1.6 nH/mm were obtained for $m = s = 10$ μm and $d = 120$ μm). Using the expressions for an ideal lossless line for the impedance, $Z_c = (L/C)^{0.5}$, and for the velocity, $v = (LC)^{-0.5}$, where L is the inductance at high frequencies (external inductance), the values for the line impedance Z_c and propagation velocity v were calculated, as illustrated in Fig. 4. These values

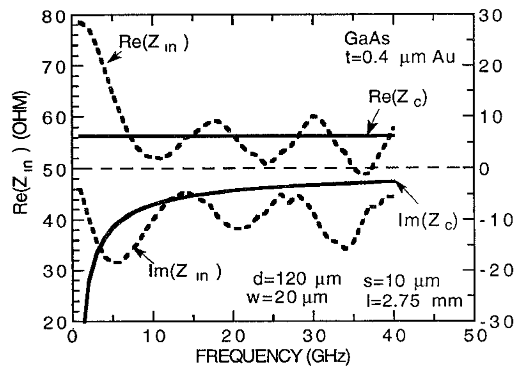

Fig. 2. Real and imaginary part of the measured line input impedance Z_{in} and the from experimental data calculated characteristic line impedance Z_c, over the range 1–40 GHz, for four lines with differing gap dimension s.

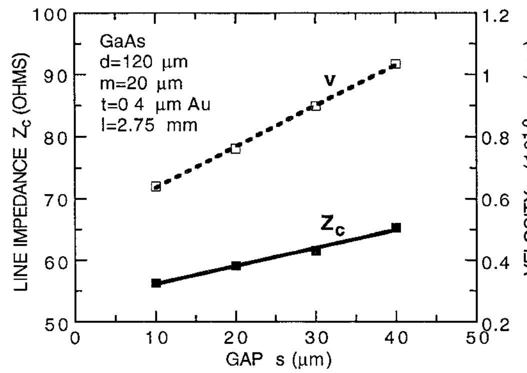

Fig. 4. From experimental data calculated line impedance Z_c and propagation velocity v of four lines with differing gap dimension s.

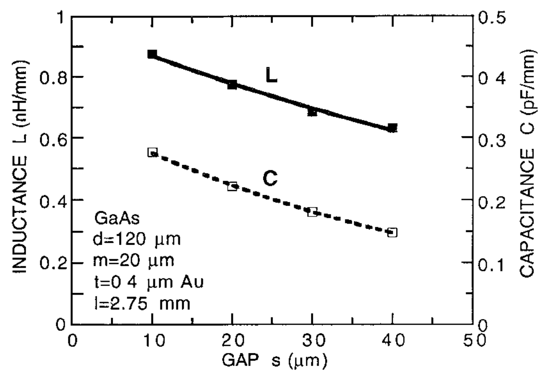

Fig. 3. Series inductance L and the parallel capacitance C of four lines with differing gap dimensions, obtained by matching the transmission line equivalent circuit to the measured S-parameters.

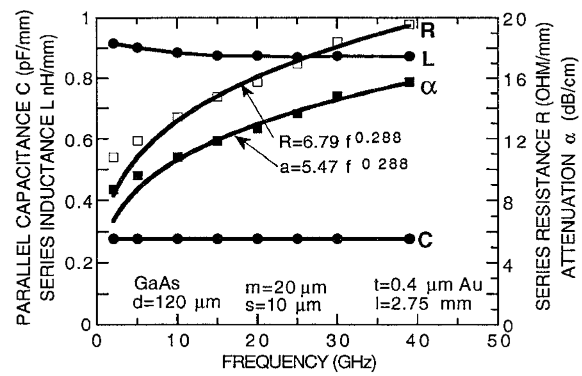

Fig. 5. Extracted values for L, R, and C per unit length, obtained by matching the transmission line equivalent circuit to the measured S-parameters, and the calculated attenuation a, of the line with gap $s = 10$ μm, as a function of frequency.

differ only slightly from those obtained from a more rigorous analysis for the lossy case [7, pp. 250–251]. A velocity of 0.64×10^{10} cm/s is obtained with a gap s of 10 μm (velocities close to 0.4×10^{10} cm/s were obtained for $m = s = 10$ μm and $d = 120$ μm). As s increases from 10 to 40 μm, the impedance increases from 55 to 65 Ohms. This only moderate change in impedance is due to the simultaneous increase in both L and C with decreasing s, as depicted in Fig. 3. For the line with gap $s = 10$ mm, the extracted values of the series inductance $L(f)$, the series resistance $R(f)$, the parallel capacitance C, and the attenuation a are illustrated in Fig. 5. The attenuation was calculated, using the approximation for a lossy line [7, p. 251], $\alpha(f) = R(f)/2Z_c$. The above attenuation about 10 GHz has been fitted as indicated [8]. Below this frequency, fitting the S-parameters to the transmission line circuit model, $R(f)$ and $\alpha(f)$ approach the dc values for the resistance (8.3 Ohms/mm) and the attenuation (8.5 dB/cm). The fitted value for $a(f)$ and the value of the velocity were used to calculate the characteristic line impedance in Fig. 2.

III. Summary and Discussion

Although area saving designs of transmission lines have been described in the past by routing the transmission line in the form of a meander [5], [6], the method presented here differs, since not the entire line, but only the center conductor has the form of a meander. The width w and the pitch p (Fig. 1) of the meander line are a small fraction of a wavelength, such that a quasi-TEM wave is still propagating along the coplanar line. This principle is also applicable to microstrip lines.

We have presented a new kind of coplanar line, where both L and C vary in the same manner while changing the gap width s, thus maintaining a rather constant impedance and resulting in a strongly varying velocity with s. This is in contrast to the conventional coplanar line with solid center conductor, where L and C vary in opposite ways with a change in gap width s, maintaining a fairly constant velocity, but resulting in a strongly varying impedance.

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